

## IMAGE DISPLAY APPARATUS AND OPTICAL SYSTEM

### Background of the Invention

### Field of the Invention

5 The present invention relates to an image display apparatus that is a so-called head mounted display or the like.

### Related Background Art

For image display apparatuses such as head mounted displays, various types of optical systems have been proposed for miniaturizing each whole apparatus. For example, Japanese Patent Application Laid-Open No. 7-333551 (corresponding to EP 687932A3) discloses an apparatus in which, a prism-like optical element consisting of rotationally asymmetrical first, second, and third surfaces is used to display an image on a display surface of an image display element as an enlarged image via the first, second, and third surfaces of the optical element.

20 Such a prism-like optical element makes it possible to correct image distortion, curvature of field, and astigmatism with a very compact, simple arrangement, and satisfy the telecentric condition with respect to the display surface.

25 Although transmissive liquid crystal displays were common as image display apparatuses at the time of the proposal in this reference the transmissive liquid

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crystal display has drawbacks that it is difficult to make the increase of pixels be compatible with miniaturization since the pixel apertures in the transmissive liquid crystal display are small.

5 Recently, since high-resolution image output apparatuses such as personal computers, and DVDs besides moving image apparatuses such as VTRs, and TV sets have increased, high-resolution image display is desired.

10 Corresponding to such a current status, it is possible to obtain a high-resolution image by using a reflective liquid crystal display whose pixel apertures can be made to be large while attaining the increase of their pixels and miniaturization. An apparatus using a  
15 reflective liquid crystal display is disclosed, for example, in Japanese Patent Application Laid-Open No. 11-125791. This reference, as shown in Fig. 15, discloses a display apparatus in which a reflective liquid crystal display 103 is directly illuminated with  
20 illumination light 102 from a light source 101 without mediacy of an optical element and an image on the liquid crystal display is guided to an observer's eye 105 to be displayed as an enlarged virtual image by a prism-like display optical element 104.

25 However, in this display apparatus, since the liquid crystal display 103 is directly illuminated with the illumination light 102 from the light source 101,

an angle  $\theta$  of the illumination light 102 and a normal of the liquid crystal display 103 becomes large.

For this reason, since the whole display apparatus becomes large and the liquid crystal display 103 is 5 greatly inclined relative to the display optical element 104, a distance between the liquid crystal display 103 and the display optical element 104 changes depending on places, and there is a problem that optical characteristics degrade.

Moreover, another display apparatus disclosed by Japanese Patent Application Laid-Open No. 11-125791 has configuration that, as shown in Fig. 16, a light source 101 is provided on the opposite side of the reflective liquid crystal display 103 with respect to the prism-like display optical element 104, the liquid crystal display 103 is illuminated with the illumination light 102 from the light source 101 through the inside of the display optical element 104 and the reflected by the liquid crystal display 103 and the reflected light from 15 the display is adapted to enter an observer's eye 105 through the inside of the display optical element 104 again. 20

However, since the utilization efficiency of the illumination light is not taken into account in such 25 conventional illumination system and some amount of light emitted from the light source is not used as illumination light, the illumination systems shown by

these conventional examples are very inefficient.

#### SUMMARY OF THE INVENTION

An object of the present invention is to provide  
5 an image display apparatus using a reflection type  
display device corresponding to high-resolution images  
such as a personal computer output, and having high  
utilization efficiency of illumination light though it  
has very simple and compact configuration.

10 In order to attain the above-described object, an  
image display apparatus according to one embodiment of  
the present invention comprises a light source which  
supplies illumination light, a reflection type display  
device which reflects the illumination light and  
15 modulates the illumination light into image light, an  
illumination optical system which guides the  
illumination light to the reflection type display  
device, and a projection optical system which guides  
the image light to an observer. The image display  
20 apparatus is characterized in that the illumination  
optical system comprises a first optical member that  
directs the illumination light toward the reflection  
type display device, and a second optical member that  
directs the illumination light toward the first optical  
25 member.

Moreover, an optical system according to another  
embodiment of the present invention has an illumination

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optical system that guides illumination light toward a reflection type display device, and a projection optical system that guides the image light, reflected by the reflection type display device, to an observer.

5       The optical system is characterized in that the illumination optical system comprises a first optical member that directs illumination light toward a reflection type display device, and a second optical member that directs the illumination light toward the  
10      first optical member.

Moreover, an image display apparatus and an optical system according to an embodiment of the present invention are characterized in that, in particular, a second optical member satisfies at least 15      one of: (a) a condition that the second optical member comprises a secondary light source generating part which generates a secondary light source with illumination light emitted from a light source, and a reflecting surface which guides illumination light  
20      other than the illumination light directly incident on the secondary light source generating part among the illumination light from the light source, to the secondary light source generating part, and emits the illumination light from the secondary light source to the first optical member; and (b) a condition that the  
25      second optical member comprises a reflecting surface which deflects a principal optical path of the

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illumination light from the light source, and emits the illumination light, reflected by the reflecting surface, to the first optical member.

5 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a structural diagram showing an image display apparatus that is a first embodiment of the present invention;

10 Fig. 2 is a perspective view of a reflecting case used for the image display apparatus of the above-described first embodiment;

Fig. 3 is an explanatory diagram of a polarization condition in the image display apparatus according to the above-described first embodiment;

15 Fig. 4 is an explanatory diagram showing a modified example of the image display apparatus according to the above-described first embodiment;

20 Fig. 5 is a structural diagram of an image display apparatus that is a second embodiment of the present invention;

Fig. 6 is a structural diagram of an image display apparatus that is a third embodiment of the present invention;

25 Fig. 7 is a structural diagram showing a modified example of the image display apparatus that is the third embodiment of the present invention;

Fig. 8 is a structural diagram of an image display

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apparatus (a modified example of the first embodiment) that is the fourth embodiment of the present invention;

Fig. 9 is a structural diagram of an image display apparatus (a modified example of the second embodiment) that is the fourth embodiment of the present invention;

Fig. 10 is a structural diagram of an image display apparatus (a modified example of the third embodiment) that is the fourth embodiment of the present invention;

Fig. 11A is a structural diagram of an image display apparatus which is a fifth embodiment of the present invention, and Fig. 11B is a structural diagram taken in the direction of arrows 11B-11B;

Fig. 12 is an explanatory view showing a coordinate system in numerical embodiments of the present invention;

Fig. 13 is a cross-sectional view of an optical system in a numerical embodiment 1;

Fig. 14 is a cross-sectional view of an optical system in a numerical embodiment 2;

Fig. 15 is a structural diagram of a conventional image display apparatus; and

Fig. 16 is a structural diagram of another conventional image display apparatus.

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#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

(Embodiment 1)

□□□□□□□□□□□□

Fig. 1 shows an image display apparatus that is a first embodiment of the present invention. The image display apparatus of this embodiment is suitable for a head-mounted display with which an observer's head is equipped. In this figure, a light source 1 consists of light emitting diodes (LEDs) and the like, and has emitting parts R1, G1, and B1 which emit color light of R (red), G (green), and B (blue) respectively. A reflecting case (a second light guide device (optical member)) 2 is hollow.

Reference numeral 3 denotes a first polarizing plate and reference numeral 4 is an illuminating prism (a first light guide device (optical member)). Reference numeral 5 is a reflective liquid crystal display panel (a reflective image display device: hereinafter, this is simply called a display panel), and reference numeral 6 is a second polarizing plate. Reference numeral 7 is a prism lens (a projection optical element), and reference numeral 8 is an observer's eye. An illumination optical system for illuminating the display panel 5 comprises the reflecting case 2 and illuminating prism 4, and a projection optical system for guiding to an observer the image light reflected by the display panel 5 comprises the prism lens 7.

Here, Fig. 2 is a perspective view of the reflecting case 2. The reflecting cases 2, as shown in

Fig. 2, is so structured to include an incident aperture I, four reflecting surfaces J1 that is aslant arranged so that it may spread vertically and horizontally toward a back side of the case from this 5 incidence aperture I, a diffusing surface (a secondary light source generating surface) K which is aslant arranged so as to obliquely face the incident aperture I in an upper part of the back side of the case, three reflecting surfaces J2 that are arranged so as to surround the right and left sides of the back side and a deepest back side of the case, and an exit aperture A that is formed in a part facing the diffusing surface K in a lower part of the back side of the case. A light source 1 is so disposed as to be adjacent to the 10 incident aperture I, and the light emitted from the light source 1 is covered and surrounded by the reflecting case 2.

Moreover, the illuminating prism 4 is arranged between the prism lens 7 and display panel 5, and a surface (reflecting and transmitting surface) 42 of the illuminating prism 4 at the prism lens side and a surface 43 at the display panel side (transmitting surface) are configured at a predetermined angle.

Furthermore, the first polarizing plate 3 is fixed  
25 to a surface 41 of the illuminating prism 4 and the  
display panel 5 is fixed to a surface 43 of the  
illuminating prism 4 with an adhesive. Moreover, the

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second polarizing plate 6 is fixed to a surface 42 of the illuminating prism 4 through a supporting member (not shown). In addition, the light source 1, the reflecting case 2, and the illuminating prism 4 are integrally secured in one piece through a supporting member not shown. Thereby, positioning of the illumination optical system and the display panel 5 with respect to the prism lens 7 can be performed in one piece.

Thus, in the image display apparatus configured like this, divergent light (illumination light) emitted from the light source 1 enters into the reflecting case 2 through the incident aperture I. The divergent light entering into the reflecting case 2 is directly incident on the diffusing surface K, or is incident on the diffusing surface K after being reflected by the reflecting surfaces J1. The illumination light incident on the diffusing surface K is reflected irregularly and diffused in this diffusing surface K, and generates a substantial secondary light source here. That is, both of a component directly entering into the diffusing surface K among the illumination light emitted from the light source 1, and another component being reflected by the reflecting surfaces J1 and entering into the diffusing surface K are used effectively, and a secondary light source is thus generated.

In addition, the illumination light from this secondary light source passes through the exit aperture A, while a part of the illumination light is reflected by the reflecting surfaces J2, and emerges from the 5 reflecting case 2.

As shown in Fig. 3, the illumination light emerging from the reflecting case 2 passes through the first polarizing plate 3, is transformed into S-polarized light, transmits through the incident 10 surface 41 of the illuminating prism 4, and enters into the illuminating prism 4. In addition, a circled X mark indicated on an optical axis line in Fig. 3 denotes that the light in this portion is S-polarized light, and an arrow denotes that the light in this 15 portion is P-polarized light. Both of S-polarized light and P-polarized light are contained in the illumination light before entering into the first polarizing plate 3, and the light becomes only S-polarized light by transmitting through the first 20 polarizing plate 3.

The S-polarized light entering into the illuminating prism 4 is totally reflected by the reflecting and transmitting surface 42 of the illuminating prism 4, transmits through the 25 transmitting surface 43 near the display panel 5 or integrally provided thereto, and illuminates the display panel 5.

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In the display panel 5, according to a video signal supplied from an image information output unit such as a personal computer and a DVD player, which are not shown, the polarized direction of light is  
5 modulated by 90° to emerge as P-polarized light. Furthermore, P-polarized light (image light) that is reflected and emerged from the display panel 5 transmits through the transmitting surface 43 again, enters into the illuminating prism 4, transmits through  
10 the reflecting and transmitting surface 42, and enters into the second polarizing plate 6.

The second polarizing plate 6 has characteristics that it makes light composed of P-polarized component transmit and absorbs light composed of S-polarized  
15 component perpendicular to the P-polarized direction, and hence, owing to this, the image light which is the P-polarized light is analyzed.

After transmitting through the second polarizing plate 6, the image light transmits through a first  
20 surface 71 of the prism lens 7, and is reflected on second and third surfaces 72 and 73 thereafter to transmit through the second surface 72 and reaches the observer's eye 8. At this time, the prism lens 7 has a positively refractive-power to make an image, displayed  
25 on the display panel 5, be a virtual image under magnification. Since three surfaces 71-73 which configure the prism lens 7 are formed by each

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rotationally asymmetrical curved surface, it is possible to observe a good image by sufficiently correcting various image aberrations (distortion etc.).

In addition, in this embodiment, a control circuit 5 is provided, the control circuit which switches the emission of the emitting parts R1, G1, and B1 of the light source 1 sequentially and controls the display panel 5 to display each color image corresponding to each emitted color synchronizing with this emission 10 switch (so-called field sequential control). Thereby, a high-definition full color image without pixel discrepancy is observable.

Thus, a bright display image can be obtained in this embodiment without increasing the emitting amount 15 of the light source 1, since a secondary light source is generated to illuminate the display panel 5 with effectively using the illumination light from the light source 1 by means of the reflecting case 2.

Further, since the principal optical path of the 20 illumination light from the light source 1 is bent by the diffusing surface (and also reflecting surface) K of the reflecting case 2, while being able to attain the miniaturization of the illumination optical system and also the whole apparatus, the allocation 25 flexibility of the light source 1 can be also enhanced.

Moreover, since illumination light and image light pass along the same area between the reflecting and

transmitting surface 42 and the transmitting surface 43 of the illuminating prism 4, it is possible to perform the illumination of a display panel 5 and the light guide of the image light to the prism lens 7 by a small optical system. Thereby, it is possible to attain the miniaturization of the illumination optical system and the whole image display apparatus as a result.

In addition, in this embodiment, an antireflection film may be attached to each surface other than the reflecting surface in the illuminating prism 4 or the prism lens 7 so that the generation of a flare or a ghost may be prevented by preventing the unnecessary reflection of light.

15 By the way, although polarizing plates 3 and 6 are used in this embodiment, when outdoor daylight (for example, sunlight) enters from the side of the observer's eye 8 at the idle time etc. of the apparatus, condensing points are made near the polarizing plates 3 and 6 by an optical action of the prism lens 7, and there is a possibility that the polarizing plates 3 and 6 may deteriorate. In order to prevent the deterioration, it is preferable to arrange the polarizing plates 3 and 6 in positions where the polarizing plates 3 and 6 are separated from the display panel 5 (for example, a position where the intensity  $I_1$  of the outdoor daylight on the polarizing plate becomes  $1/10$  or less of the intensity  $I_0$  of that

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on the display panel 5).

Moreover, in this embodiment, in order to prevent that light other than the illumination light from the secondary light source enters into the illuminating prism 4, and reaches the observer's eye 8, it can be performed lest unnecessary light should enter into an eye by painting black paint having optical-absorption nature by making surfaces, other than optically active surfaces such as a side of the illuminating prism 4, into the diffusing surfaces.

Furthermore, instead of the above-described reflecting case 2, as shown in Fig. 4, it can be also performed to provide a second light guide device composed of a plurality of diffusing surfaces K1 and K2. In this case, it can be also performed to make it possible to efficiently use light from a light source 1 by providing curvature for each diffusing surface.

Moreover, in this embodiment, the first polarizing plate 3 is fixed to the surface 41 of the illuminating prism 4, the second polarizing plate 6 is fixed to the surface 42, and the panel 5 is fixed to the surface 43 with an adhesive. Hence, it is possible to perform positioning to the prism lens 7 in one piece since the light source 1, the reflecting case 2, and the illuminating prism 4 are secured in one piece through the supporting member not shown.

In addition, in this embodiment, the explanation

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is made to the case where the illumination light transmitting through the first polarizing plate 3 is S-polarized light and the image light modulated by the display panel 5 is P-polarized light. Nevertheless, 5 the illumination light transmitting through the first polarizing plate 3 can be P-polarized light, and the image light modulated by the panel 5 does not need to be P or S-polarized light but can be polarized light in any direction.

10 (Embodiment 2)

Fig. 5 shows an image display apparatus that is a second embodiment of the present invention. In addition, the same reference numerals are assigned to components similar to those in the first embodiment.

15 In this embodiment, instead of the reflecting case 2 in the first embodiment, a diffusing prism (a second light guide device) 12 is used.

The diffusing prism 12 is formed in a prism-like shape of being filled with a medium having a refractive 20 index larger than one. In addition, its entire shape is similar to the reflecting case 2 in the first embodiment. Namely, the diffusing prism 12 comprises an incident surface I near which a light source 1 is disposed, four reflecting surfaces J1 aslant arranged 25 so that it may spread vertically and horizontally toward a back side of the prism from this incident surface I, the diffusing surface K (secondary light

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source generating surface) that is aslant arranged so that the diffusing surface K may aslant face the incident surface I in an upper back side of the prism, three reflecting surfaces J2 arranged so that the surfaces J2 may surround the right and left sides of the back side and the deepest back side of the prism, and the exit surface A formed in a portion which faces the diffusing surface K in a lower back side of the prism.

10 In addition, in Fig. 5, the three emitting parts R1, G1, and B1 of the light source 1 are arranged in the direction perpendicular to the drawing sheet.

In this embodiment, divergent light (illumination light) emitted from the light source 1 enters into the diffusing prism 12 through the incident surface I. The divergent light entering into the diffusing prism 12 directly enters into the diffusing surface K, or enters into the diffusing surface K after being reflected by the reflecting surfaces J1. The illumination light entering into the diffusing surface K is reflected irregularly and diffused in this diffusing surface K, and generates a substantial secondary light source here. That is, both of a component, directly entering into the diffusing surface K among the illumination light emitted from the light source 1, and another component, being reflected by the reflecting surfaces J1 and entering into the diffusing surface K, are used

effectively, so that a secondary light source is thus generated.

In addition, the illumination light from this secondary light source emerges from the diffusing prism 12 through the exit surface A, while a part of the illumination light is reflected by the reflecting surfaces J2, and the illumination light transmits through the first polarizing plate 3 to enter into the illuminating prism 4. Hereafter, similarly to the first embodiment, the image light emerged from the display panel 5 reaches the observer's eye 8.

Thus, similarly to the first embodiment, a bright display image can be obtained in this embodiment without increasing the emitting amount in the light source 1, since a secondary light source is generated to illuminate the display panel 5 with effectively using the illumination light from the light source 1 in the diffusing prism 12.

Moreover, since the principal optical path of the illumination light from the light source 1 is bent by the diffusing surface (also serving as a reflecting surface) K of the diffusing prism 12, while being able to attain the miniaturization of the illumination optical system and also the whole apparatus, the allocation flexibility of the light source 1 can be also enhanced.

In addition, the reflecting surfaces  $J_1$  have a

characteristic of making light with an incident angle, smaller than a total-reflection angle, transmit therethrough, and making light with an incident angle not smaller than the total-reflection angle reflect.

5 Owing to this, the diffusing prism 12 can be miniaturized.

Moreover, in this embodiment, the first polarizing plate 3 is secured to the surface 41 of the illuminating prism 4, the second polarizing plate 6 is 10 secured to the surface 42, and the panel 5 is secured to the surface 43. Hence, it is possible to perform positioning of those members to the prism lens 7 in one piece since the light source 1, the diffusing prism 12, and the illuminating prism 4 are secured in one piece 15 through a supporting member not shown.

(Embodiment 3)

Fig. 6 shows an image display apparatus that is a third embodiment of the present invention. In addition, the same reference numerals are assigned to 20 components similar to those in the first and second embodiments.

In this embodiment, instead of the reflecting case 2 or diffusing prism 12 in the first or second embodiment, a light guide prism (a second light guide 25 device) 22 is provided.

The light guide prism 22 is formed in a truncated-cone shape, and the incident surface I near which the

light source 1 is disposed is formed in its top, the diffusion and exit surface K which is made to diffuse and emit the illumination light is formed in its soffit. Moreover, the inside surface of the light 5 guide prism 22 is a reflecting surface J which reflects toward a diffusing and exit surface K a part of the illumination light which enters from the incident surface I.

In this embodiment, the divergent light 10 (illumination light) emitted from the light source 1 enters into the light guide prism 22 through the incident surface I. The divergent light entering into the light guide prism 22 directly enters into the diffusing and exit surface K, or it is reflected by the 15 reflecting surface J and enters into the diffusing and exit surface K. The illumination light entering into the diffusing and exit surface K is diffused in this diffusing and exit surface K, and generates a substantial secondary light source here. That is, a 20 secondary light source is generated by effectively using both of a component of the illumination light emitted from the light source 1, which directly enters into the diffusing and exit surface K, and a component which is reflected by the reflecting surface J and 25 enters into the diffusing and exit surface K.

In addition, the illumination light from this secondary light source emerges from the light guide

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prism 22, transmits through the first polarizing plate 3, and enters into the illuminating prism 4. Hereafter, the image light emerged from the display panel 5 like the first and second embodiments reaches the observer's eye 8.

Thus, in this embodiment, like the first and second embodiment, the illumination light from the light source 1 is effectively used by the light guide prism 22, a secondary light source is generated, and the illumination light illuminates the display panel 5. Hence, a bright display image can be obtained without increasing the emitting amount in the light source 1.

In addition, although, in this embodiment, a case  
that the exit surface of the light guide prism 22 is  
made to be a diffusing surface is explained, as shown  
in Fig. 7, it can be also performed to generate a  
secondary micro light source unit by two-dimensionally  
arranging micro lens groups M on an exit surface.

#### ( Embodiment 4 )

20 In the above-described first to third embodiments,  
a case is explained, the case that illumination light  
diffused by the reflecting case 2, the diffusing prism  
12, or the light guide prism 22 is made to directly  
12, or the light guide prism 22 is made to directly  
enter into the first polarizing plate 3 and is led to  
the illuminating prism 4. However, as shown in Figs. 8  
25 to 10, it can be performed to provide a prism plate  
(directional element) PS, where an exit surface is made

to be sawtooth-shaped or concavo-convex, between the reflecting case 2, diffusing prism 12, or light guide prism 22, and the first polarizing plate 3.

Owing to this, since it is possible to make the  
5 diffused illumination light enter into the first  
polarizing plate 3 and also illuminating prism 4 with  
enhancing the directivity of the diffused illumination  
light, it is possible to efficiently illuminate the  
display panel 5.

## 10 (Embodiment 5)

Fig. 11A shows an image display apparatus which is a fifth embodiment of the present invention. Fig. 11B is a view taken in the direction of arrows 11B-11B. In addition, the same reference numerals are assigned to components similar to those in the above-described embodiments.

This embodiment is configured so that two sets of light sources (each has emitting parts of three colors, R, G, and B) 1a and 1b are arranged near two sides of an approximately plate-like diffusing prism plate 32, and hence illumination lights from light sources 1a and 1b is made to enter into the diffusing prism plate 32 from a direction perpendicular to a plane (drawing sheet) including a visual axis Ax inflected.

25 A top face of the diffusing prism plate 32 is  
configured as the diffusing surface K, and two sets of  
light sources 1a and 1b are arranged near an

undersurface of the diffusing prism plate 32. For this reason, the divergent light (illumination light) from two sets of light sources 1a and 1b are directly incident on the diffusing surface K obliquely from the 5 lower side (i.e. from the opposite side), or are reflected on a reflecting and transmitting surface J' which is the undersurface of the diffusing prism plate 32 and are incident on the diffusing surface K.

The illumination light incident on the diffusing surface K is reflected irregularly and diffused in this diffusing surface K, and generates a substantial secondary light source here. That is, a secondary light source is generated with effectively using both of a component, directly entering into the diffusing surface K among the illumination lights emitted from the light sources 1a and 1b, and another component, being reflected by the reflecting surface J' and entering into the diffusing surface K.

In addition, the illumination light from this 20 secondary light source emerges from the reflecting and transmitting surface J' of the diffusing prism plate 32, transmits through the first polarizing plate 3, and enters into the illuminating prism 4. Hereafter, similarly to the above-described embodiments, the image 25 light emerged from the display panel 5 reaches the observer's eye 8.

Thus, a bright display image can be also obtained

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in this embodiment without increasing the emitting amount in the light sources 1a and 1b, since a secondary light source is generated to illuminate the display panel 5 with effectively using the illumination 5 lights from the light sources 1a and 1b in the diffusing prism plate 32.

Moreover, in this embodiment, the diffusing prism plate 32 is configured by stacking the prism plates (directional element) PS1 and PS2, whose exit surfaces 10 each are sawtooth-shaped or concavo-convex, with changing the orientation by 90 degrees from each other.

Owing to this, since it is possible to make the diffused illumination light enter into the first polarizing plate 3 and also illuminating prism 4 with 15 enhancing the directivity of the diffused illumination light in two directions, it is possible to efficiently illuminate the display panel 5.

In addition, although, in this embodiment, a case that two sets of light sources are used is explained, three or more sets of light sources can be used.

Moreover, although, in each of the above-described 20 embodiments, a case that each light source having an emitting part of three colors, R, G, and B is used is explained, a white light source may be used for the light source and color filters may be provided for 25 pixels of the display panel.

(Numerical embodiments)

Next, the numeric data of an observation optical system used for the present invention will be expressed.

Since the optical system in this embodiment is configured from decentered surfaces, so as to express a form of the optical system, as shown in Fig. 12, an absolute coordinate system (X, Y, Z) and a local coordinate system (x, y, z) are set.

An origin of the absolute coordinate system is set to the center O of an observer's desirable eye here, its Z-axis is set in the direction in which the point O is passed and an image center can be seen. Therefore, the Z-axis of the absolute coordinate system is a straight line that passes through the point O and is perpendicular to a pupil plane, and is on a symmetric plane (sheet of the drawing) of the optical system. The Y-axis is a straight line which makes the angle of 90° counterclockwise to the Z-axis through the origin O on the above-described symmetric plane. The X-axis is a straight line which passes through the origin O and intersects perpendicularly to the Y- and Z-axes.

As for the allocation of each surface, an origin  $O_i$  of the local coordinates of each surface is set in the absolute coordinates ( $d_{xi}$ ,  $d_{yi}$ ,  $d_{zi}$ ). A shape of each surface is expressed as a function based on the local coordinates.

An angle  $Tilt_i$  which the Z-axis of the absolute

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coordinate system and the z-axis of the local coordinates make is defined to be positive, when making a counterclockwise angle within the sheet of the drawing to the x-axis of the local coordinates, as shown in Fig. 12.

5 shown in Fig. 12.

A shape of an optical surface in the numerical embodiments is a shape which has the aspherical surface expressed by the Zernike polynomials as a shape function showing a secondary curved surface, and hence each shape is expressed in the following function.

$$\begin{aligned}
z = & \frac{c(x^2+y^2)}{1 + \{1-c^2(x^2+y^2)\}^{1/2}} \\
& + c4(x^2-y^2) \\
& + c5(-1+2x^2+2y^2) \\
& + c9(-2y+3x^2y+3y^3) \\
& + c10(3x^2y-y^3) \\
15 & + c11(x^4-6x^2y^2+y^4) \\
& + c12(-3x^2+4x^4+3y^2-4y^4) \\
& + c13(1-6x^2+6x^4-6y^2+12x^2y^2+6y^4) \\
& + c19(3y-12x^2y+10x^4y-12y^3+20x^2y^3+10y^5) \\
& + c20(-12x^2y+15x^4y+4y^3+10x^2y^3-5y^5) \\
20 & + c21(5x^4y-10x^2y^3+y^5) \\
& + c22(x^6-15x^4y^2+15x^2y^4-y^6) \\
& + c23(6x^6-30x^4y^2-30x^2y^4+6y^6-5x^4+30x^2y^2-5y^4) \\
& + c24(15x^6+15x^4y^2-15x^2y^4-15y^6-20x^4+20y^4+6x^2-6y^2) \\
& + c25(20x^6+60x^4y^2+60x^2y^4+20y^6-30x^4-60x^2y^2- \\
& 25 \quad 30y^4+12x^2+12y^2-1)
\end{aligned}$$

Here,  $c$  is the curvature of each surface, and when  $r$  is let to be the basic radius of curvature of each surface, curvature  $c$  is  $c=1/r$ . Moreover,  $c_j$  is the aspherical surface coefficient of the Zernike polynomials in each surface.

In this embodiment, since the optical surface is symmetrical to YZ plane and the coefficient of each term which becomes asymmetric about the X-axis is 0, it is removed from the above formulas.

Moreover, lens data is set so that the origin O of the absolute-coordinates is a first surface S1 and an image display surface is an image plane, and is defined as an optical system where reverse-pursuit is performed for the propagation of actual light.

15 <<Numerical embodiment 1>>

Image angle in x direction =  $\pm 9.0^\circ$ , Image angle in y direction =  $\pm 12.0^\circ$

Prism refractive index (2nd-5th surfaces) n=

1.571

20 S1 r:  $\infty$  d: 31.03 n: 1.0000

S2 dY 7.83 dZ 31.03 Tilt 3.50

r :-100.433

c4 :-3.307e-03

c5 :-1.165e-03

c9 :-6.272e-05

c10:-7.142e-05

c11: 3.936e-07

c12: 1.640e-06

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c13:-1.848e-06      c19:-2.900e-08      c20: 1.268e-08

$$c21: -2.956e-07 \quad c22: 3.968e-09 \quad c23: -2.127e-09$$

c24: 1.666e-09 c25:-8.306e-10

S3 dY 1.27 dZ 39.72 Tilt -21.50

5 r : -39.332

$$c4 := 1.389e-03 \quad c5 := 1.135e-04 \quad c9 := 8.011e-06$$

c10:-5.002e-06 c11: 2.126e-07 c12: 5.227e-07

c13:-4.186e-07                    c19: 2.591e-08                    c20:-2.986e-08

c21:-2.274e-08      c22:-8.657e-10      c23:-5.791e-10

10 c24: 5.953e-10 c25:-5.290e-10

S4 dY 7.83 dz 31.03 Tilt 3.50

r :-100.433

$$c4 : -3.307e-03 \quad c5 : -1.165e-03 \quad c9 : -6.272e-05$$

c10: -7.142e-0 c11: 3.936e-07 c12: 1.640e-06

15 c13:-1.848e-06 c19:-2.900e-08 c20: 1.268e-08

c21:-2.956e-07      c22: 3.968e-09      c23:-2.127e-09

c24: 1.666e-09      c25: -8.306e-10

S5 dY 14.79 dZ 38.10 Tilt 70.53

r : 37.866

c4 : 7.662e-03

c5 : 8.422e-04

c9 : -4.588e-04

c10: 3.757e-04

c11: 5.015e-05

c12: 4.182e-06

c13: 1.465e-05

c19:-2.861e-07

c20: 2.195e-07

5

c21:-4.250e-06

c22:-1.699e-07

c23:-6.247e-08

c24:-2.618e-08

c25:-1.152e-10

S6 dY 15.57 dZ 38.44 Tilt 71.34

r:  $\infty$  d: 3.50 n: 1.5163

S7 dY 17.46 dZ 41.39 Tilt 38.53

10 r:  $\infty$  d: 0.10 n: 1.0000

S8 dY 20.26 dZ 39.28 Tilt 38.53

r:  $\infty$  d: 1.10 n: 1.5230

S9 r:  $\infty$  d: 0.00 n: 1.0000

<<Numerical embodiment 2>>

15 Image angle in x direction =  $\pm 15.0^\circ$ , Image angle in  
y direction =  $\pm 11.2^\circ$

Prism refractive index (2nd-5th surfaces) n= 1.570

S1 r:  $\infty$  d: 36.95 n: 1.0000

S2 dY -23.69 dZ 36.95 Tilt 10.49

20 r : 255.629

c4 : 6.085e-04

c5 :-4.977e-04

c9 : 8.657e-06

c10:-3.669e-05                    c11: 3.013e-07                    c12:-1.910e-07

c13:-5.180e-08                    c19:-5.840e-10                    c20:-9.577e-10

c21:-1.450e-09                    c22:-9.686e-11                    c23:-2.075e-11

c24: 1.196e-11                    c25:-1.758e-11

5        S3    dY   -0.31    dZ   41.09    Tilt   -22.91

r : -71.945

c4 :-2.459e-03                    c5 :-1.110e-03                    c9 :-5.627e-05

c10: 9.527e-07                    c11:-7.886e-08                    c12:-5.893e-07

c13: 1.109e-07                    c19: 8.032e-09                    c20:-1.540e-08

10                                    c21: 1.105e-08                    c23: 1.914e-10

c24: 5.234e-11                    c25: 9.073e-11

S4    dY   -23.69    dZ   36.95    Tilt   10.49

r : 255.629

c4 : 6.085e-04                    c5 :-4.977e-04                    c9 : 8.657e-06

15                                    c10:-3.669e-05                    c12:-1.910e-07

c13:-5.180e-08                    c19:-5.840e-10                    c20:-9.577e-10

c21:-1.450e-09                    c22:-9.686e-11                    c23:-2.075e-11

c24: 1.196e-11                    c25:-1.758e-11

S5 dY 15.97 dZ 37.39 Tilt 52.17

r :-367.524

c4 : 1.211e-03                    c5 :-3.804e-03                    c9 :-8.203e-04

5                                    c10: 7.935e-04                    c11:-3.264e-05                    c12: 1.544e-05

                                  c13:-1.167e-05                    c19: 0.000e+00                    c20: 0.000e+00

                                  c21: 0.000e+00                    c22: 0.000e+00                    c23: 0.000e+00

                                  C24: 0.000e+00                    C25: 0.000e+00

S6 dY 19.02 dZ 36.97 Tilt 44.16

10                                    r:  $\infty$  d: 5.28 n: 1.5163

S7 dY 21.58 dZ 41.87 Tilt 20.66

                                  r:  $\infty$  d: 0.85 n: 1.0000

S8 dY 18.16 dZ 43.37 Tilt 20.66

                                  r:  $\infty$  d: 1.10 n: 1.5230

15                                    S9 r:  $\infty$  d: 0.00 n: 1.0000

                                  Figs. 13 and 14 are optical-path diagrams when  
                                  optical paths are reverse-pursued from an eye side in  
                                  the numerical embodiments 1 and 2, respectively. Each  
                                  symbol in the figures expresses a symbol of each  
                                  surface cited in numerical embodiments.

20                                    Here, since a direction where a field angle is  
                                  wider is a horizontal direction when observing, a

reflecting surface is configured in the numerical embodiment 1 so that a lateral direction to the observer becomes the Y direction, and the reflecting surface is configured in the numerical embodiment 2 so that vertical direction to the observer becomes the Y direction.

As explained above, according to this embodiment, a secondary light source is generated by using both of an illumination-light component which enters directly to a secondary light source generating surface provided in a second light guide device among the illumination light from a light source, and another illumination light component led to the secondary light source generating surface by the reflection on a reflecting surface similarly provided in the second light guide device. Furthermore, a reflective image display device is illuminated by making the illumination light from this secondary light source enter into the first light guide device. Hence, a bright display image can be obtained without increasing the emitting amount in the light source since it is possible to effectively use the illumination light from the light source.

In addition, if a directional element providing an action of enhancing the directivity of the illumination light which emerges from the second light guide device (that is, light being diffused and so on in the secondary light source generating surface to emerge

therefrom) and enters into the first light guide device is provided, it is possible to more efficiently illuminate the reflective image display device.

Moreover, the principal optical path of the  
illumination light is bent by the reflecting surfaces  
of the second light guide device and it is made to lead  
the illumination light to the first light guide device.  
Hence, in comparison with a case that the principal  
optical path of the illumination light from a light  
source is not bent and a lens system for the formation  
of parallel light from the illumination light or  
condensing the illumination light is disposed between  
the light source and first light guide device, the  
illumination optical system and also whole apparatus  
can be made more compactly, and the allocation  
flexibility of the light source can be enhanced.

Moreover, if a device having a reflecting and transmitting surface which reflects incident illumination light toward a reflective image display device and transmits image light from the reflective image display device toward the projection optical element is used as a first light guide device, it is possible to miniaturize an illumination optical system since at least parts of an area where the illumination light passes and an area where the image light passes overlap in the first light guide device.

Moreover, it is possible to favorably correct the

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distortion of an image by making at least one of the optical surfaces (reflecting surfaces are included), provided in a projection optical element, to be a rotationally asymmetrical surface.

5 Furthermore, if a second polarizing plate which  
analyzes the image light from the reflective image  
display device is provided between the reflecting and  
transmitting surface of the first light guide device  
and the projection optical element while providing the  
first polarizing plate for making illumination light,  
10 emitted from the second light guide device, enter into  
the first light guide device as polarized light, it is  
possible to display a better image by separately  
controlling polarization conditions of the illumination  
15 light and image light.

Moreover, a plurality of light emitting portions for emitting respective different colors of the illumination light are provided as a light source when a color image is displayed, while sequentially switching the emitting time of the light from these plurality of emitting portions, a reflective image display device is made to perform the time-sequential display of images according to colors of the illumination light with synchronizing with the timing of emission switching of the plurality of above-described emitting portions. Then, it becomes possible to perform high-resolution image display without pixel discrepancy by color.